

two divisions was obtained for the reflection reading. From this an approximate idea of the intensity of the reflected component may be obtained. Half the total radiation gave a deflection of 120 divisions. The intensity of the reflected component, with a thickness of 0·45 mm., is therefore 1/120th part of the total amount of incident radiation, on the assumption, which is only approximate, that the galvanometer deflections were symmetrical. When the thickness was reduced to 0·3 mm., no reflected component could be detected, though the receiver was made extremely sensitive.

"An Examination into the Registered Speeds of American Trotting Horses, with Remarks on their value as Hereditary Data." By FRANCIS GALTON, D.C.L., F.R.S. Received November 29,—Read December 16, 1897.

It is strange that the huge sums spent on the breeding of pedigree stock, whether of horses, cattle, or other animals, should not give rise to systematic publications of authentic records in a form suitable for scientific inquiry into the laws of heredity. An almost solitary exception to the disregard, shown by breeders and owners, of exact measurements for publication in stud books, exists in the United States with respect to the measured speed of "trotters" and "pacers" under defined conditions. The performance of 1 mile by a trotter, harnessed to a two-wheeled vehicle, carrying a weight of not less than 150 lbs. inclusive of the driver, in 2 minutes 30 seconds qualifies him for entry in the Trotting Register, giving him, as it were, a pass-degree into a class of horses whose several utmost speeds or "records" are there published. To avoid prolixity I will not speak particularly of pacers (pace = amble), since what will be said of the trotters applies in general principle to them also.

The great importance attached to high speed, and the watchfulness of competitors, have resulted in evolving a method of timing trotters which is generally accepted as authoritative. The length of the track is scrupulously measured, and numerous other conditions are attended to, that shall ensure the record being correct, with an attempted exactitude to the nearest quarter of a second. A race against time, even if exact to the nearest quarter of a second, is by no means so close a measure of the speed of a horse relatively to his competitors, as the differential method of ordinary races. The speed of 1 mile in 2' 30", or of 1760 yards in 150 seconds, is equivalent to about 12 yards in 1 second. Now, the length of a horse when extended at full trot is half as long again as his height at the withers—as I gather from the instantaneous photographs of Muybridge—and consequently is hardly ever as much as



3 yards. Therefore at a 2' 30" speed a horse travels through his whole length in a quarter of a second. In an ordinary English race a winner by half a length gains a notable victory, while a neck or even a head in advance is sufficient to establish his priority. Therefore the record of the speed of a horse to the nearest quarter of a second is by no means an absurd refinement. It is, of course, very difficult under the exciting circumstances of a race to measure time with such precision as that. I tested the value of these entries as follows:—If quarter seconds were noted with exactness the entries of 0, $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ would be approximately equal in number; they would also be equal if they were set down at random without bias, but if there be a bias towards favourite numbers its effects would be apparent. I extracted a few hundred entries, and found the relative frequency of the 0, $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ to be almost exactly as 1, 3, 2, and 1. Consequently the $\frac{1}{4}$ is on the average three times as great a favourite as either the 0 or the $\frac{3}{4}$, and the $\frac{1}{2}$ is twice as much a favourite as they are. It is evident that the $\frac{1}{4}$ seconds are not strictly trustworthy, but it may well be urged that their entry is preferable to their total disregard.

I was informed that a trifling laxity was tolerated when a horse had just but only just failed to qualify, an allowance of $\frac{1}{4}$ of a second in his favour being commonly made. So that a speed of 2' $30\frac{1}{4}$ " would usually be reckoned as 2' 30". I shall return to this point further on.

The system of timing and of registering records began more than fifty years ago, and was developed and improved by degrees. In 1892 a considerable change was made in the conditions by the introduction of bicycle wheels with pneumatic tyres, which produced a gain of speed, the amount of which is much discussed, but which a prevalent opinion rates at 5 seconds in the mile. Thenceforward the records are comparable on nearly equal terms. All trotting performances up to the 2' 30" standard are registered in the large and closely printed volumes of 'Wallace's Year Book,' published under the authority of the American Trotting Association. Vols. 8—12 refer to the years 1892-6, and it is from the entries in these that the following remarks are based.

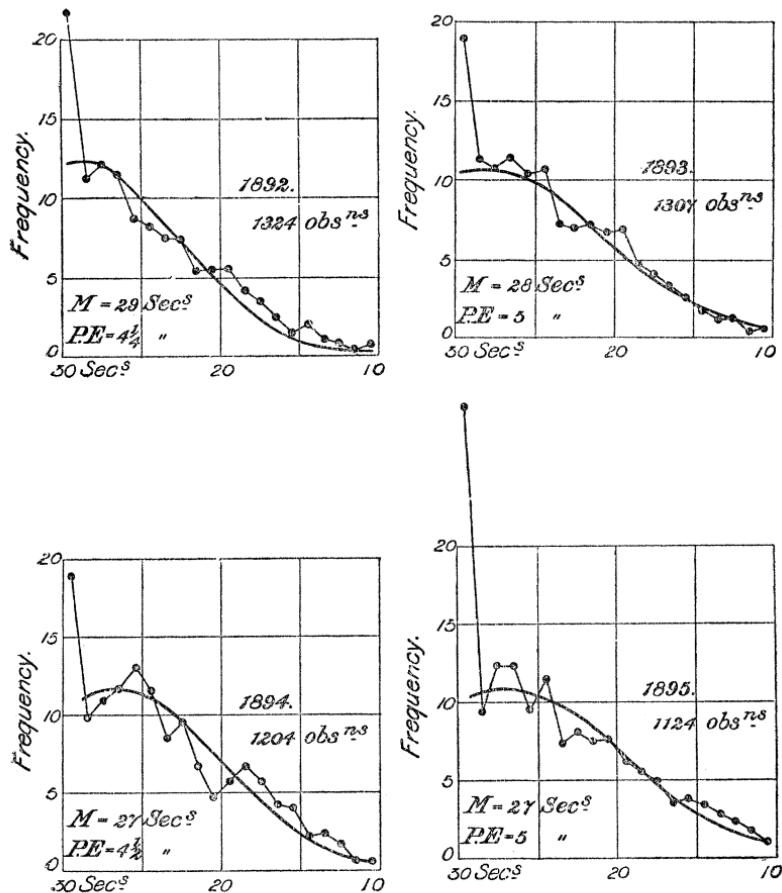
The object of my inquiry was to test the suitability of these trotting (and pacing) records for investigations into the laws of heredity. Their trustworthiness was of course one point to be ascertained, another was to obtain a just notion of the proper principle on which marks for speed should be awarded, as, for instance, in the following example:—Suppose a particular ancestor, whom we will call A, of a certain horse has a record of 2' 30", and that another ancestor in the same degree, whom we will call B, has a record of 2' 10", how are their joint influences to be estimated? Will it be the

same on the average as that of two horses each having the speed of 2' 20", or will it be something altogether different? In short, is the arithmetical the most appropriate mean or not? It would be a strong presumption in the affirmative, if the relative frequency of the various speeds should correspond approximately with those determined by the normal law of frequency, because if they do so they would fall into line with numerous anthropometric and other measures which have been often discussed, and which, when treated by methods in which the arithmetic mean was employed, have yielded results that accord with observed facts. Whether the speeds do or do not occur with the normal frequency had therefore to be ascertained. So my inquiry had two objects: first, did the run of the observations suggest a tolerably smooth curve? Secondly, was that curve a tolerable approach to the curve of normal frequency?

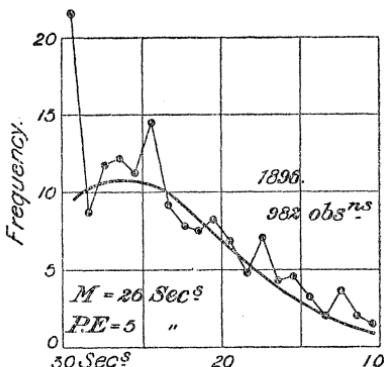
The investigation was troublesome and tedious. It was necessary to pick out from a large collection the names of those stallions, geldings, and mares (all three being equally efficient trotters), whose records had been made in the year under consideration, and who also had arrived at maturity, that is, who were not less than five years old, and therefore had had time to show their full powers. Had younger horses been included, the frequency of the slower records would have been much increased. Assisted by a friend, the appropriate entries were underlined in the printed volumes, then one of us read them out, and the other ticked them down in the appropriate column of a page ruled for the purpose. Finally the marks in each column were counted. In this way 5705 extracts were made from the entries for the years 1892-96; they were not subsequently verified, so some few omissions are probable. Anyhow they form a fair and large sample, and are quite sufficient for the present purpose.

The discussion of this material resulted in rather bulky tables, which it is needless to reproduce here, because their contents are given in an adequate and much simpler manner by the accompanying diagrams. The successive columns in the table are represented in the diagrams by imaginary columns that stand on corresponding bases. They run as follows:—The first column, counting from the left, contains the percentage value of all observations recorded as 2' 29·0", 29 $\frac{1}{4}$ ", 29 $\frac{1}{2}$ ", or 29 $\frac{3}{4}$ "; that is of all under 30 down to 29 inclusive (the minutes being here omitted for brevity). The second column referred to 28·0", 28 $\frac{1}{4}$ ", 28 $\frac{1}{2}$ ", and 28 $\frac{3}{4}$ ", and so on with the rest. Consequently the dot in the diagram which indicates the percentage number of observations, according to the side scale, stands in the middle of its own imaginary column. For example, that of the 2' 28" set stands vertically above the point that lies half way

between 28 and 29 on the scale along the base. The dots are connected by thin lines to show the trace or curve of the observations. The smooth curves are those of normal frequency, calculated from the values of the mean (M) and of the probable error (P.E.), which are given in the diagrams.



Leaving aside for the moment the strange pinnacle that rises on the extreme left of every diagram, we see that the traces of the observations run very roughly, but not intolerably so. In each diagram they seem to be disposed about a fundamentally smooth curve. Considering the smallness of the interval, namely, only 1 second, that separates the observations assigned to each pair of successive columns, together with the experience derived from other kinds of statistical curves, it seems to me that the run of the obser-



vations is good enough to certify their general trustworthiness. As regards the pinnacle it is a different matter, and is one which when beginning work, as I did, on the 1892 entries only, was very perplexing. However, by persevering with the other years it became increasingly plain that the pinnacle was a false maximum; in 1896 it was certain that the true maximum lay well within the portion of the curve included in the diagram. The explanation of the pinnacle then became obvious; it was that the tolerance granted to those horses who failed by only a little to qualify themselves, was extended considerably beyond the quarter second for which I was prepared.* The cases of 2' 30" were few; they do not appear in the diagram, but their addition would be quite insufficient to remove the difficulty. If the pinnacle were distributed among two adjacent columns outside and to the left of the diagram it would smooth away the incongruity, so I suspect that cases of "under 2' 32" and down to 2' 30" are habitually rated at a trifle less than 2' 30". Consequently I had no hesitation in wholly disregarding the entries that helped to make the pinnacle, namely, the whole of those contained in the first column to the left in every one of the diagrams. The course thereupon became clear and straightforward. When fixing upon the mean for each year, I was somewhat biassed by the entries in the adjacent years; similarly as to the probable error. Now that the curves are drawn I see that somewhat better fits might have been made, but they are close enough to show the existence of a fair amount of correspondence between the observed values and those calculated according to the law of normal frequency. It is near enough to remove hesitation in working with the arithmetic mean.

* [Jan. 20.—I have since learnt that the conditions of timing are too rigorous to justify this inference; also that the very numerous efforts simply to secure a standard record, and thenceforward to cease training, may be a chief cause of the pinnacle.]

I now come to the fundamental purpose of this memoir, which is to point out the existence in the registers of the American Trotting Association, of a store of material most valuable to inquirers into the laws of heredity, which accumulates and increases in value year by year. Unfortunately it lies buried to a hopeless depth, partly because the published part of the registers refers only to standard trotters. It appears to be buried simply through the omission of having its importance insisted on. The published volumes of the 'Trotting Register' contain numerous elaborate tables, but lacks one that should include the names and pedigrees of those horses concerning whose antecedents enough is known to make their pedigrees serviceable to investigators.

It is hardly worth while to discuss hereditary influence on speed, in the case of any horses, unless the records of at least their sires and of their dams, and those of each of their four grandparents, as well as their own record, are all known. Even in this case (according, at least, to my own theory) one quarter of the hereditary influences are unknown and have to be inferred. It is practically impossible to make an adequate collection of the names of horses who fulfil the above conditions out of the entries in the 'Trotting Register,' each search requiring many cross references and occupying a long time, while the number of futile searches before attaining a success is great. On the other hand, the breeders and possessors of these notably bred horses must be familiar with the required facts, and would assuredly be delighted to have them known. There need, therefore, be little difficulty in obtaining materials for the much desired table. In the meantime I am sending circulars to the chief breeders in America in hopes of making a start.

The great need for genealogical data of an exact numerical kind, by those who prosecute inquiries into the laws of heredity, is the justification that I offer for submitting these remarks to the Royal Society.